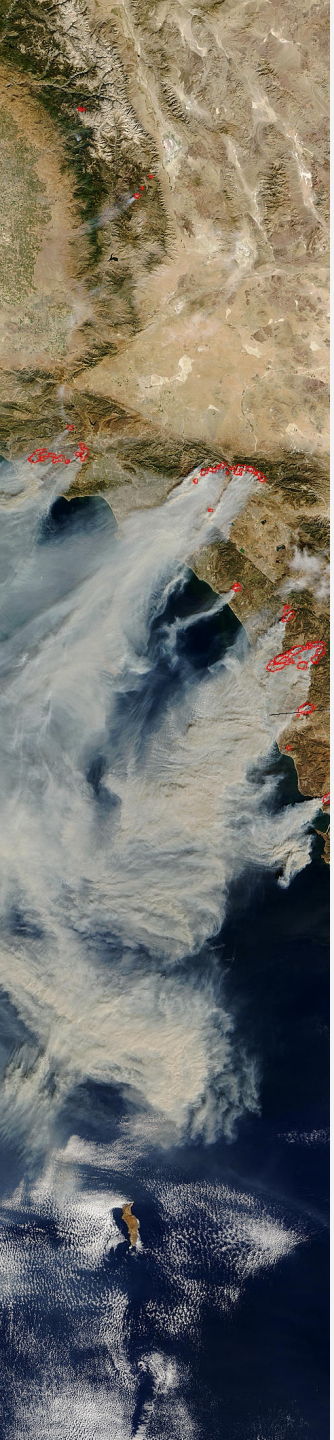


National Aeronautics and Space Administration

ARSET
Applied Remote Sensing Training
http://arset.gsfc.nasa.gov
@NASAARSET

MERRA-2 Reanalysis

Pawan Gupta, Melanie Follette-Cook

(Based on Slides from Arlindo da Silva and GMAO Team)

Satellite Remote Sensing of Air Quality

September 19-21, 2017
University of California, Riverside

Learning Objectives

By the end of this presentation, you will be able to:

- Learn about NASA MERRA Reanalysis data sets
- Learn to access data and tools for AQ applications

Why data assimilation?

- Models are useful, but have difficulty specifying emissions, microphysical processes, and transport leads to large uncertainties

- While there are a large number of aerosol sensors, there are still blind spots:
  - Measurements are usually vertically integrated
  - Diurnal cycle is not represented by polar orbiters

- Data assimilation can act as an integrator of model and observational information and a conveyor of past observations

What is reanalysis, and why do we do it?

What

- Relies on models to interpret, relate, and combine different observations from multiple sources
- A consistent reprocessing of Earth system observations using a modern, unchanging data assimilation system
- A successful reanalysis ***requires*** a good forecast model combined with bias-corrected and quality controlled observations

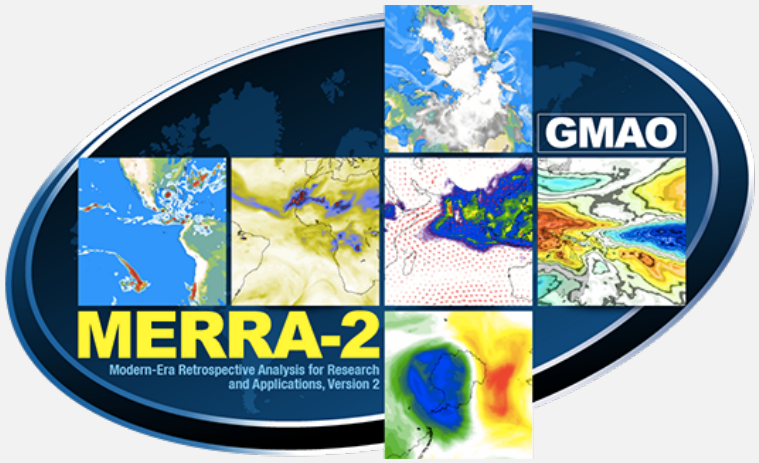
Why

- Produces multi-decadal, gridded datasets that estimate a large variety of Earth system variables, including ones that are not directly observed
- Has become fundamental to research and education in the Earth sciences

MERRA Reanalysis

https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

- Long-term, model-based analyses of multiple datasets using a fixed assimilation system
  - GEOS (Goddard Earth Observing System Model)
- The **M**odern-**E**ra **R**etrospective analysis for **R**esearch and **A**pplications (MERRA) provides data beginning in 1980 and runs a few weeks behind real-time
- MERRA-2 includes meteorology, stratospheric ozone, and aerosols at a spatial resolution of a 0.5° × 0.66° grid



Source: https://gmao.gsfc.nasa.gov/reanalysis/

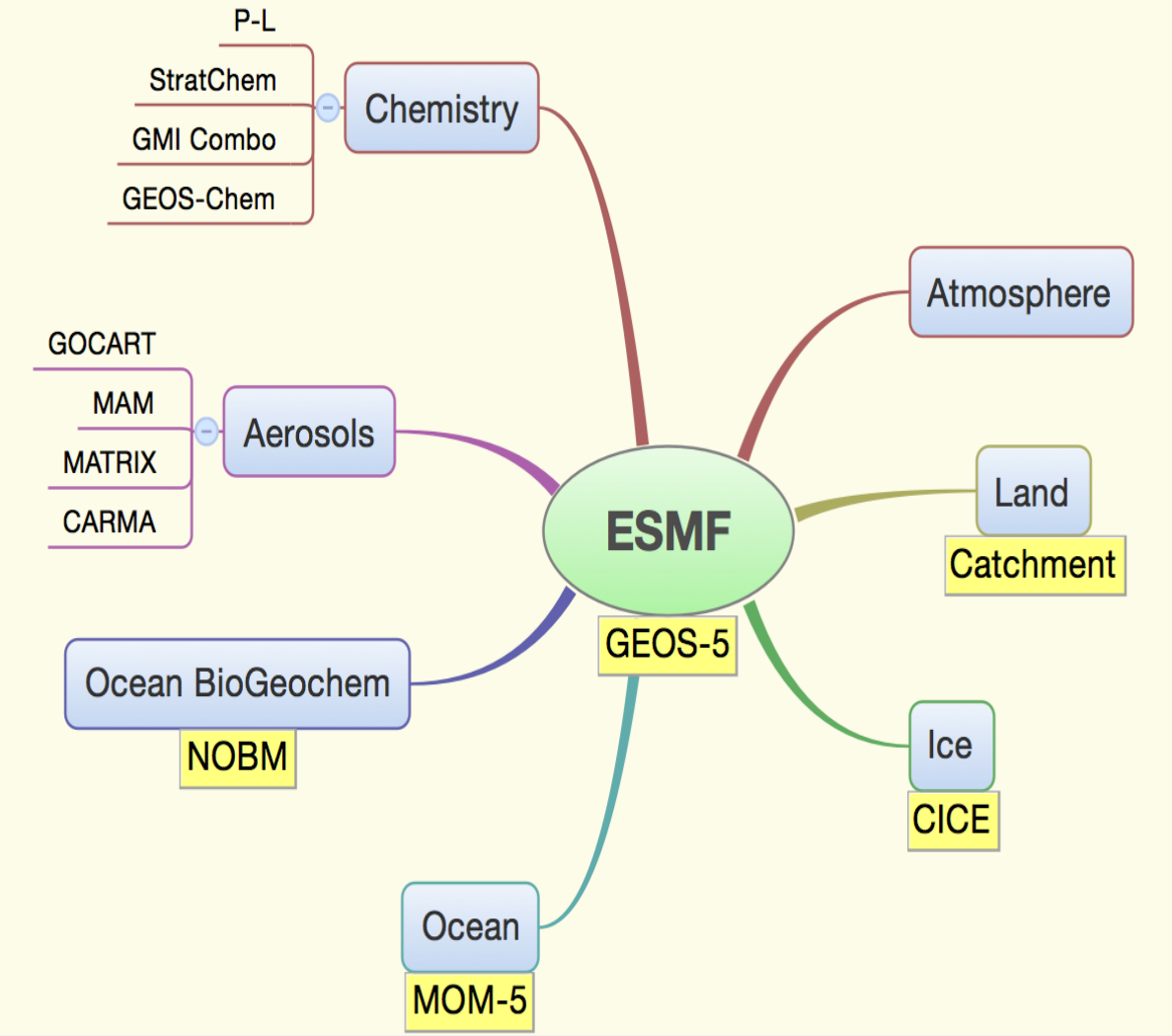
GEOS-5 Reanalysis Activities

Name	Nominal Resolution	Period	Aerosol Data	Available
MERRA-1	50 km	1979 – present	NONE	now
MERRAero	50 km	2002 – present	MODIS C5	now
Forward Processing for Inst. Teams	50 km	1997 - present	MODIS C5	In progress
NCA	25 km	2010 – 2011	MODIS C5, MISR	Now
MERRA-2	50 km	1979 – present	AVHRR, MODIS C5, MISR, AERONET	Summer 2015
MERRA-2 Dynamical Downscaling	**12.5 km**	**2000 – 2014**	**AVHRR, MODIS C5, MISR, AERONET**	**Q4 2015**

GEOS-5

Earth System Model

- Components coupling via the Earth System Model Framework (ESMF)
- Aerosol and chemistry radiatively coupled to GCM
- Applications
  - Seasonal forecasts
  - Weather and aerosol NRT forecasts
  - Reanalysis
  - Observing System Simulation Experiments (OSSEs)



Radiance Assimilation into MERRA

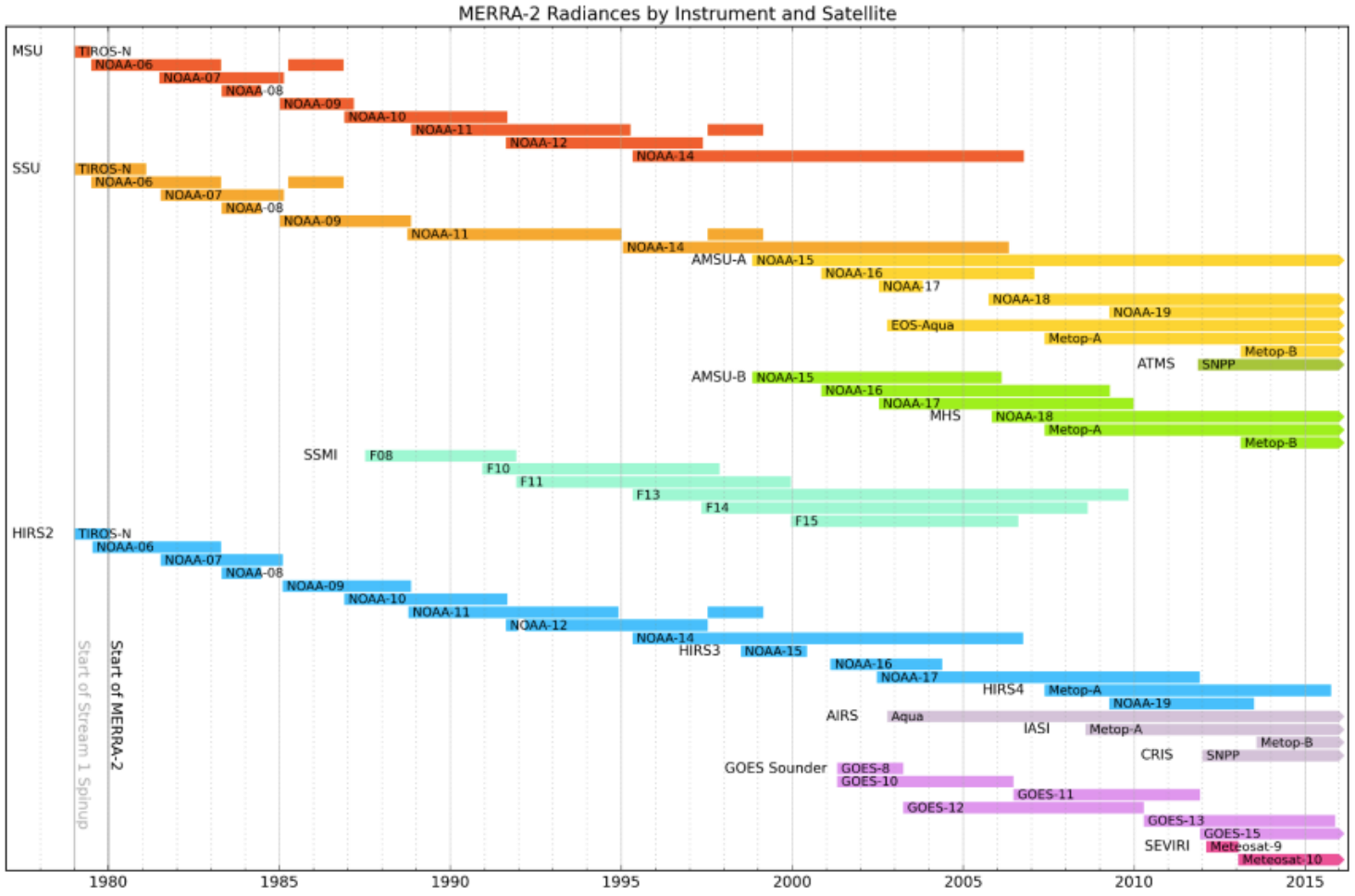
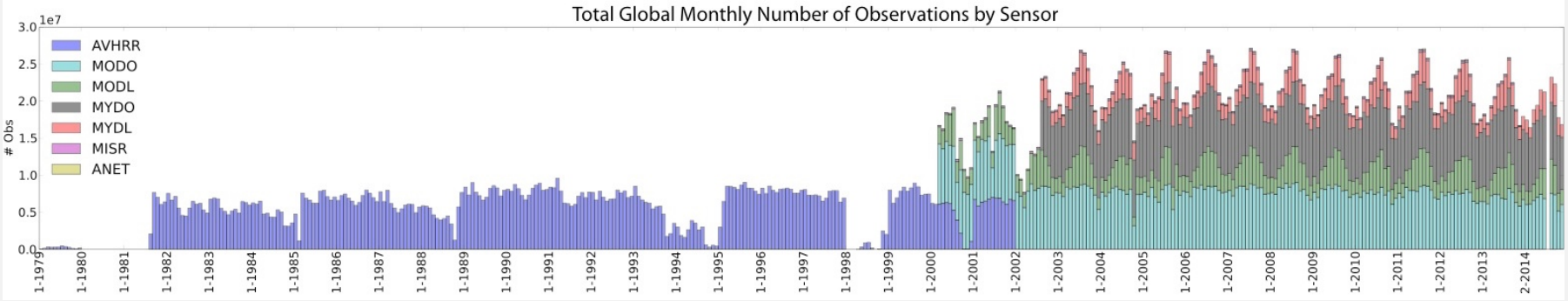


Figure 5 - Timeline of satellite radiance observations over the entire MERRA-2 period. Each bar is colored by instrument type and represents a satellite from which the instrument measured.

Aerosol Observing System

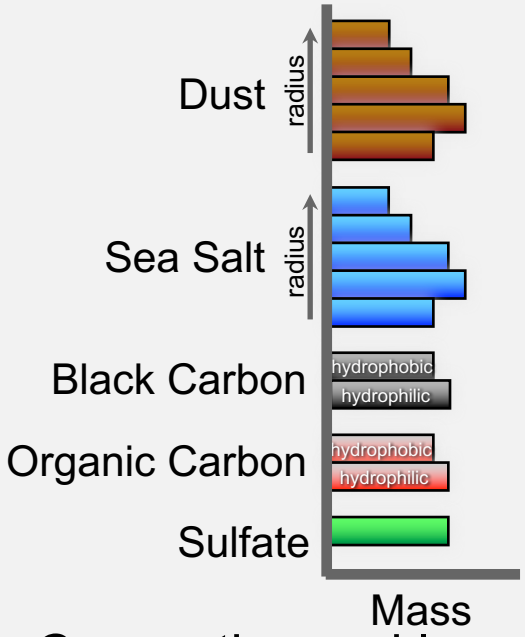
Sensor	Period	Remarks
AVHRR*	1979 – 2002	PATMOS-x; NNR; Ocean Only
AERONET	1999 – 2015	Ground-Based Stations
MODIS Terra*	2000 - present	C5; NNR; Separate Land and Ocean
MODIS Aqua*	2002 – present	C5; NNR; Separate Land and Ocean
MISR	2000 – 2014	Bright Surfaces (albedo > 0.15)

Total global monthly number of AOD observations (below), sensors marked with * multiplied by 10^7)



GOCART in GEOS-5

- Based on the Goddard Chemistry, Aerosol, Radiation and Transport Model (Chin et al. 2002)
- Sources and sinks for 5 non-interactive species



Dust: wind and topographic source, 5 mass bins

Sea Salt: wind driven source, 5 mass bins

Black Carbon: anthropogenic & wildfire source, mass hydrophobic & hydrophilic

Organic Carbon: anthropogenic, biogenic, and wildfire source, mass hydrophobic and hydrophilic

Sulfate: anthropogenic and wildfire source of SO_2, oxidation to SO_4 mass

- Convective and large scale wet removal
- Dry deposition (and sedimentation for dust and sea salt)
- Optics based primarily on OPAC

MERRA-2 Emissions

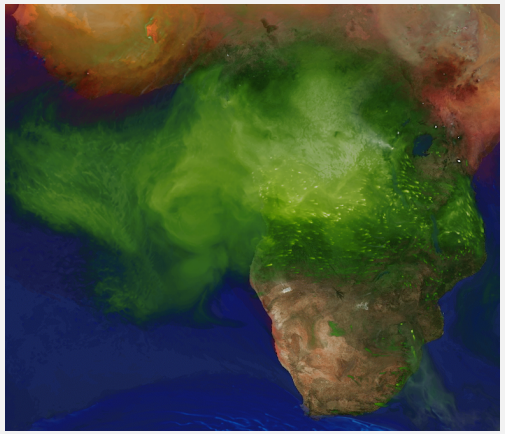


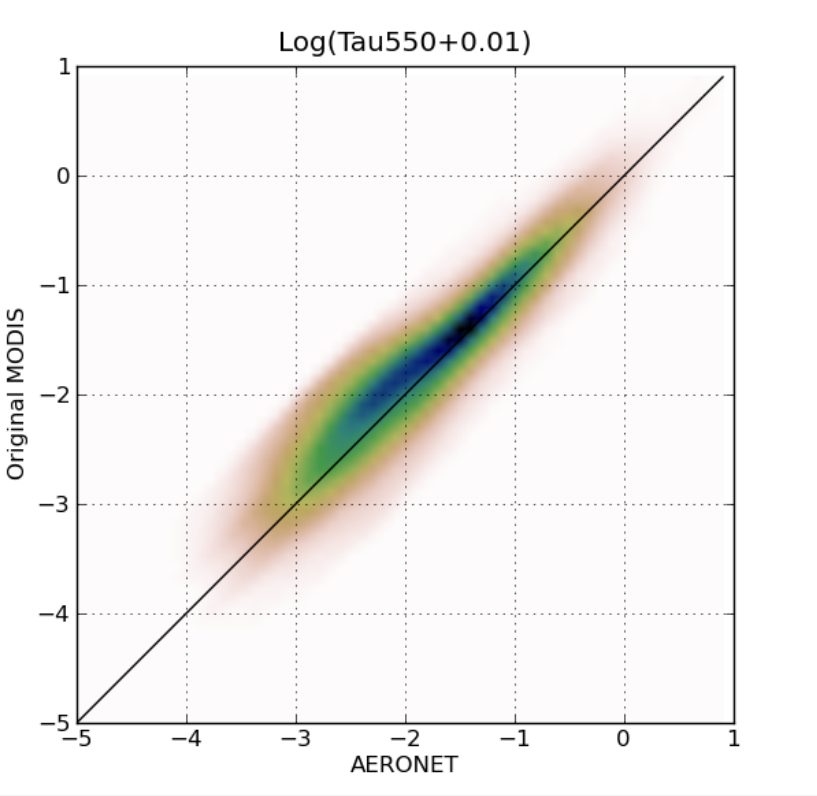
Table 1: Aerosol emissions databases (native temporal and spatial resolutions).

Aerosol Type	Source	Temporal Resolution	Spatial Resolution[a,b]
Dust[c]	Wind-driven emissions w/**?** source	Annual-mean climatology	0.3125° × 0.25°
Sea Salt	Wind-driven emissions	Model	Model
Volcanic (SO_2)	AeroCom Phase II (HCA0 v2)	Daily	Point-sources
Biogenic terpene	GEIA	Monthly-mean climatology	2° × 2.5°
DMS	Lana *et al.* 2011	Monthly-mean climatology	1° × 1°
Biomass Burning (SO_2, OC and BC)[d]	HFED	Monthly-varying	0.5
Biomass Burning (SO_2, OC and BC)[e]	QFED-2.4r6	Daily	0.3125° × 0.25°
Anthropogenic SO_2 and SO_4	EDGARv4.2 (Energy + Non-Energy)	Annually-varying	1° × 1°
Anthropogenic OC and BC	AeroCom Phase II (HCA0 v1)	Annually-varying	1° × 1°
Ship (SO_2, SO_4, OC, BC)	EDGARv4.1 and **?**	Annually-varying	1° × 1°
Aircraft (SO_2)	AeroCom Phase II (HCA0 v1)	Monthly-varying	1° × 1.25° × 72-levels

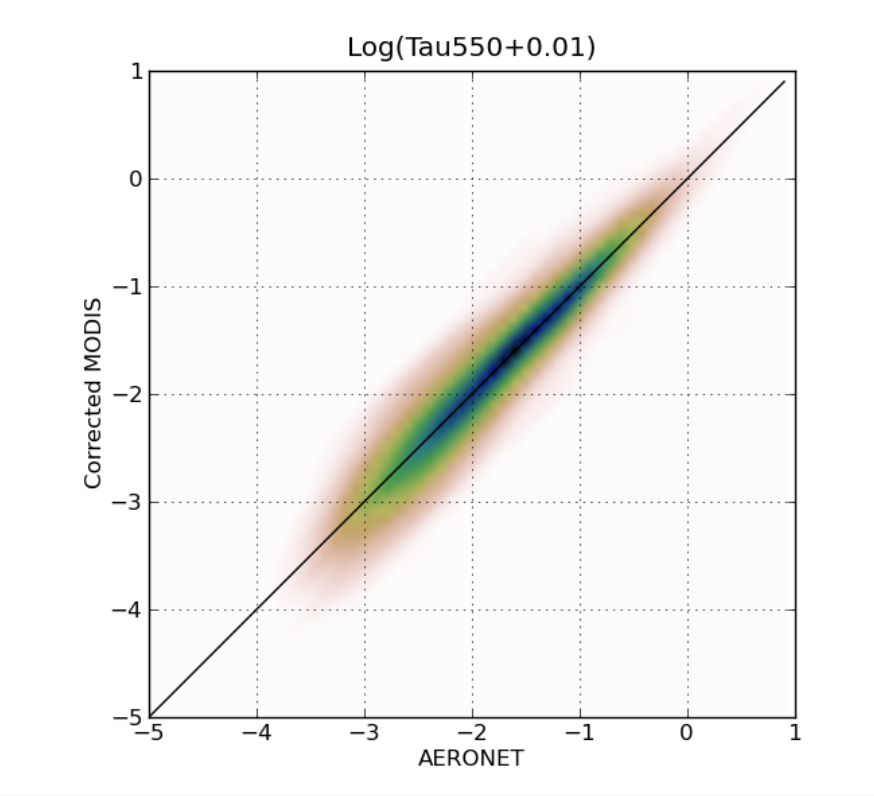
[a] Model = MERRA-2 time-step of 30 minutes with spatial resolution of 0.5° latitude × 0.625° longitude.
[b] latitude × longitude
[c] Resolution is for source map (Ginoux *et al.* 2001); wind-driven emissions at model time-step.
[d] Streams 1-3; Y1979-Y2010
[e] Stream 4; Y2010-onward

Observational Bias in AODs

Original MODIS AOD



Bias Corrected AOD

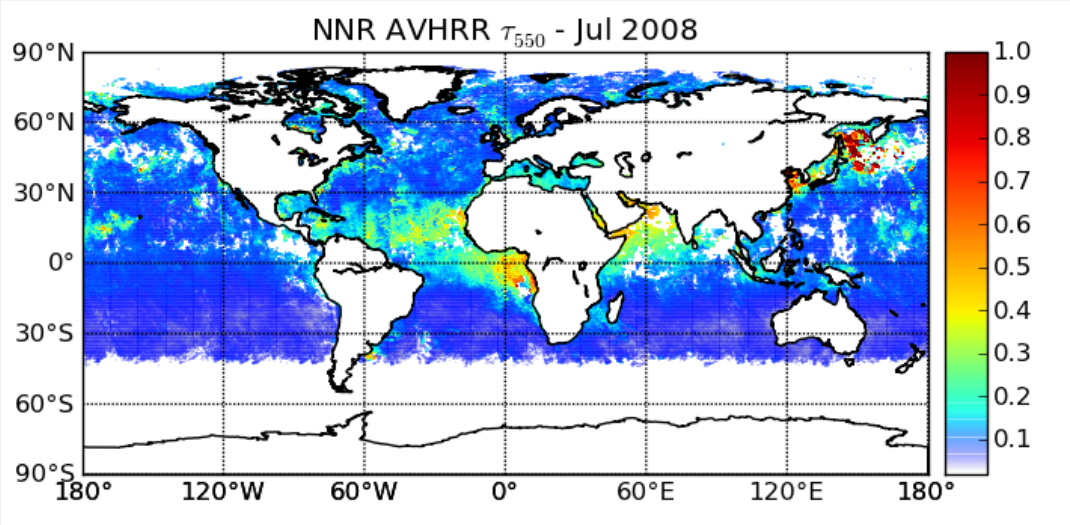


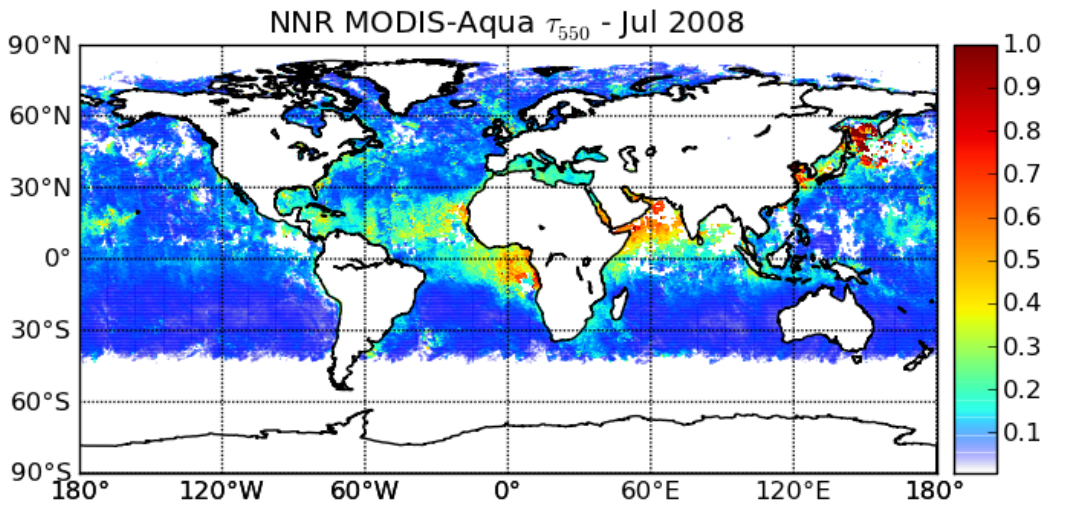
MODIS Neural Net AOD Retrievals trained on AERONET

Observing System Homogenization

In order to minimize spurious jumps due to relative instrument biases, MERRA-2 uses AERONET as a reference in a series of Neural Net Retrievals (NNR) based on reflectances from:

- MODIS Collection 5
- PATMOS-X AVHRR

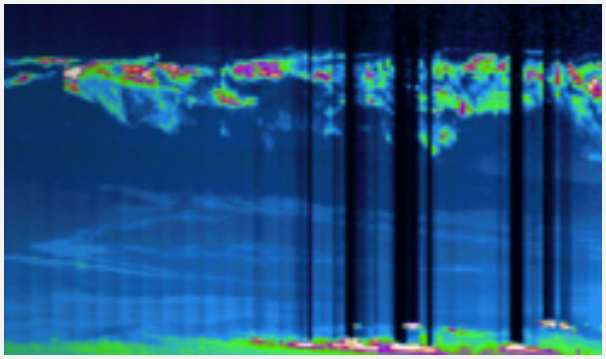




Evaluation & Intercomparisons

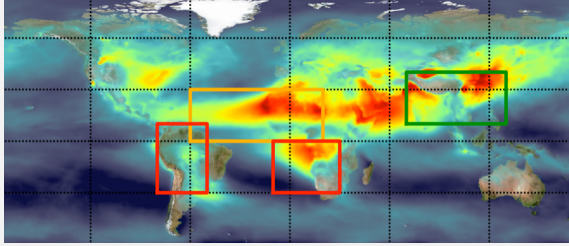
MERRA-2 Aerosol Evaluation Highlights

Using Independent Observations

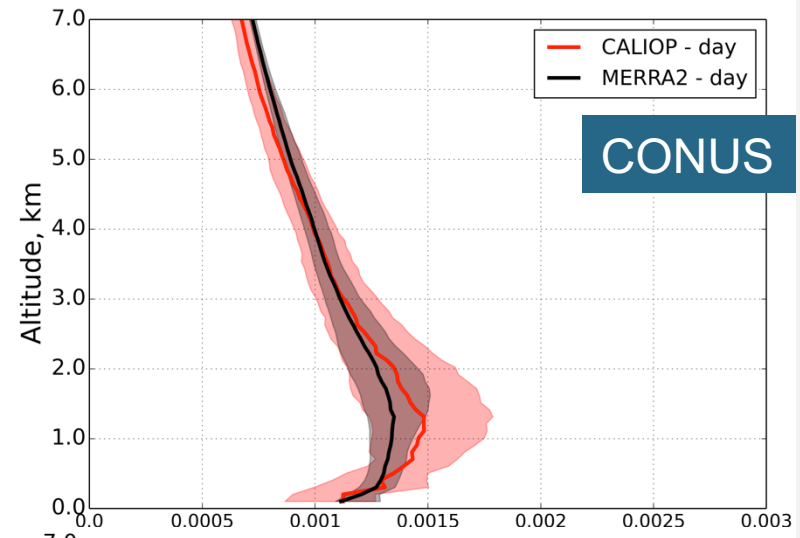


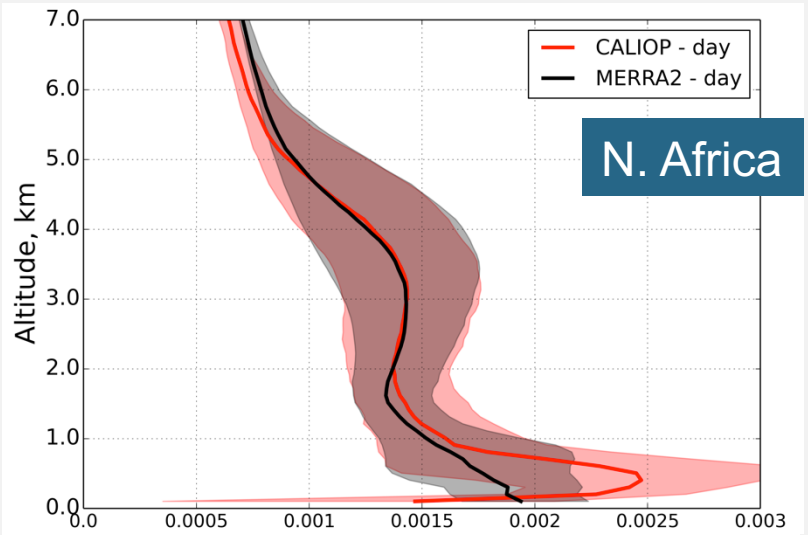
Vertical Structure

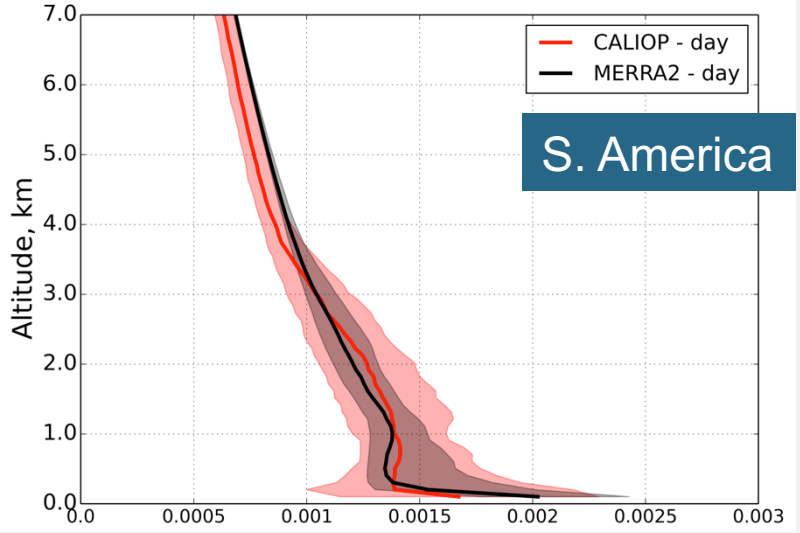
Comparison to CALIOP

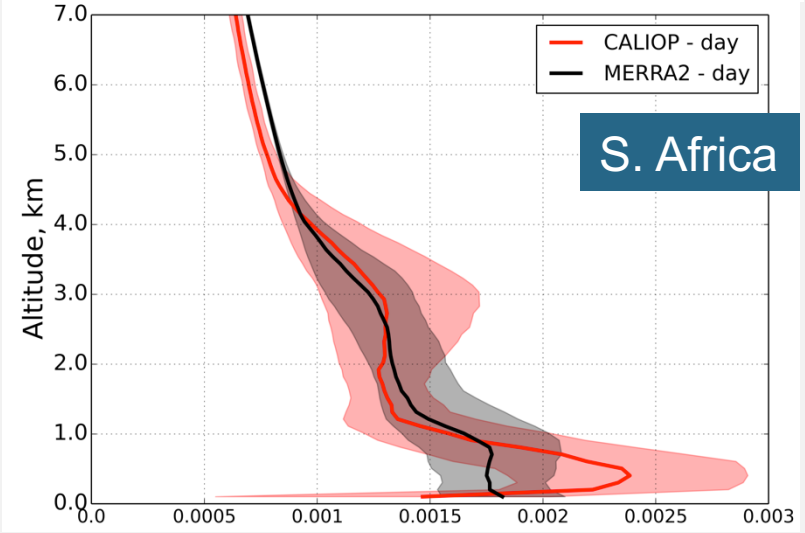


Attenuated Backscatter km^{-1} sr^{-1}



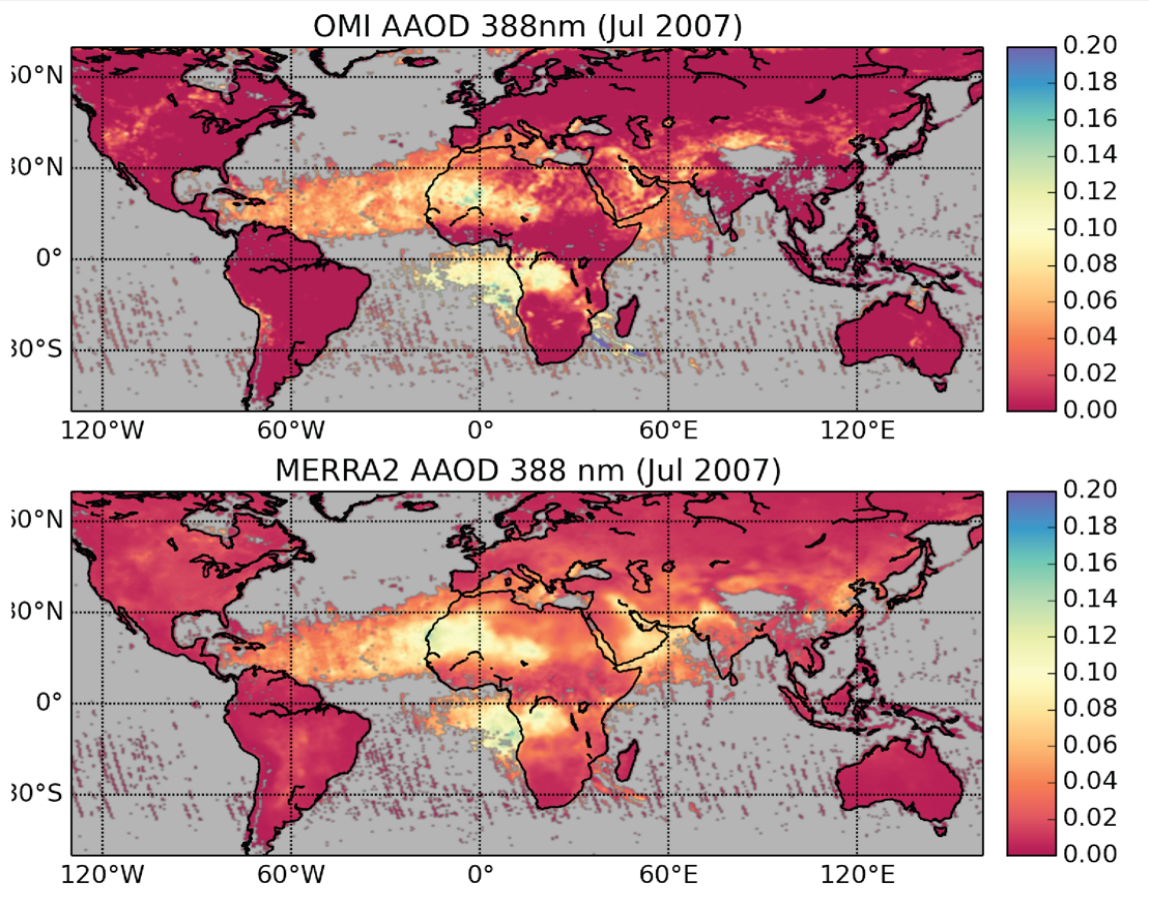




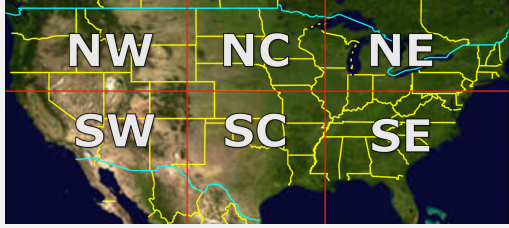


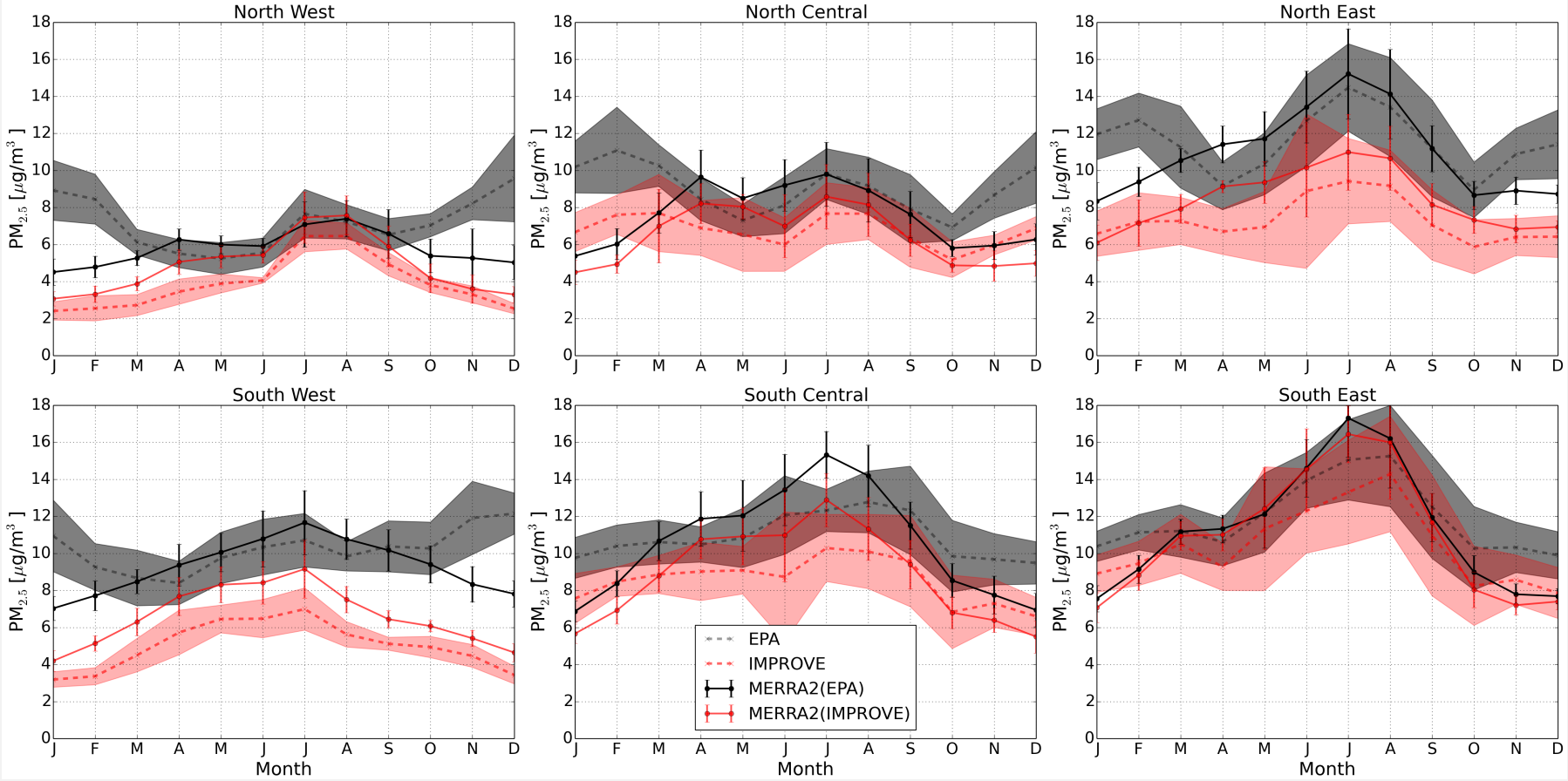
Aerosol Absorption

- Comparison of MERRA-2 Absorption Optical Depth (AAOD) with OMI retrievals
- Good agreement for African dust and smoke
- North American biomass burning underestimated according to OMI



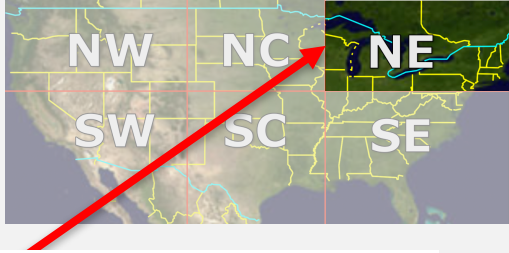
$PM_{2.5}$ (Total) Regional Climatology



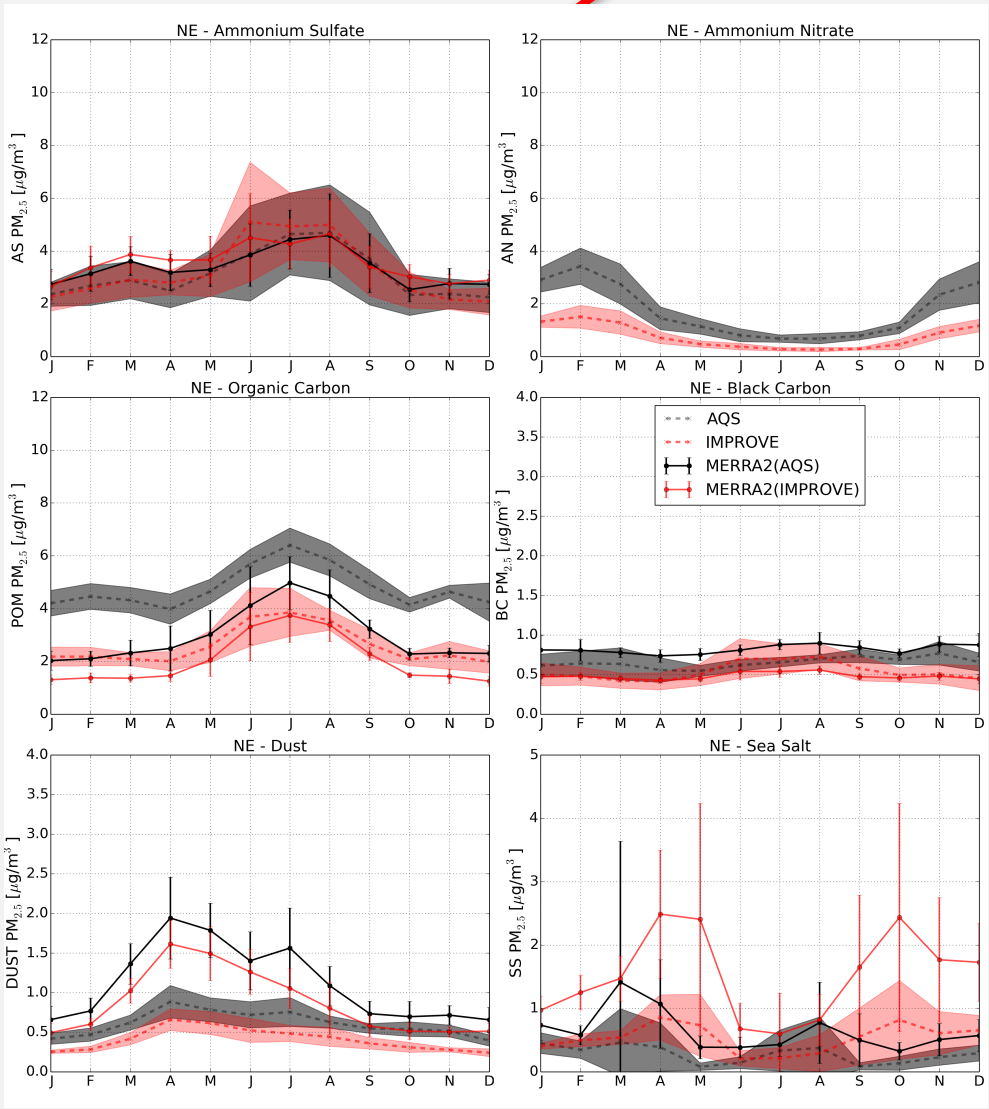


Comparison with in-situ measurements after *Buddy Check*

$PM_{2.5}$ by Species in the Northeast



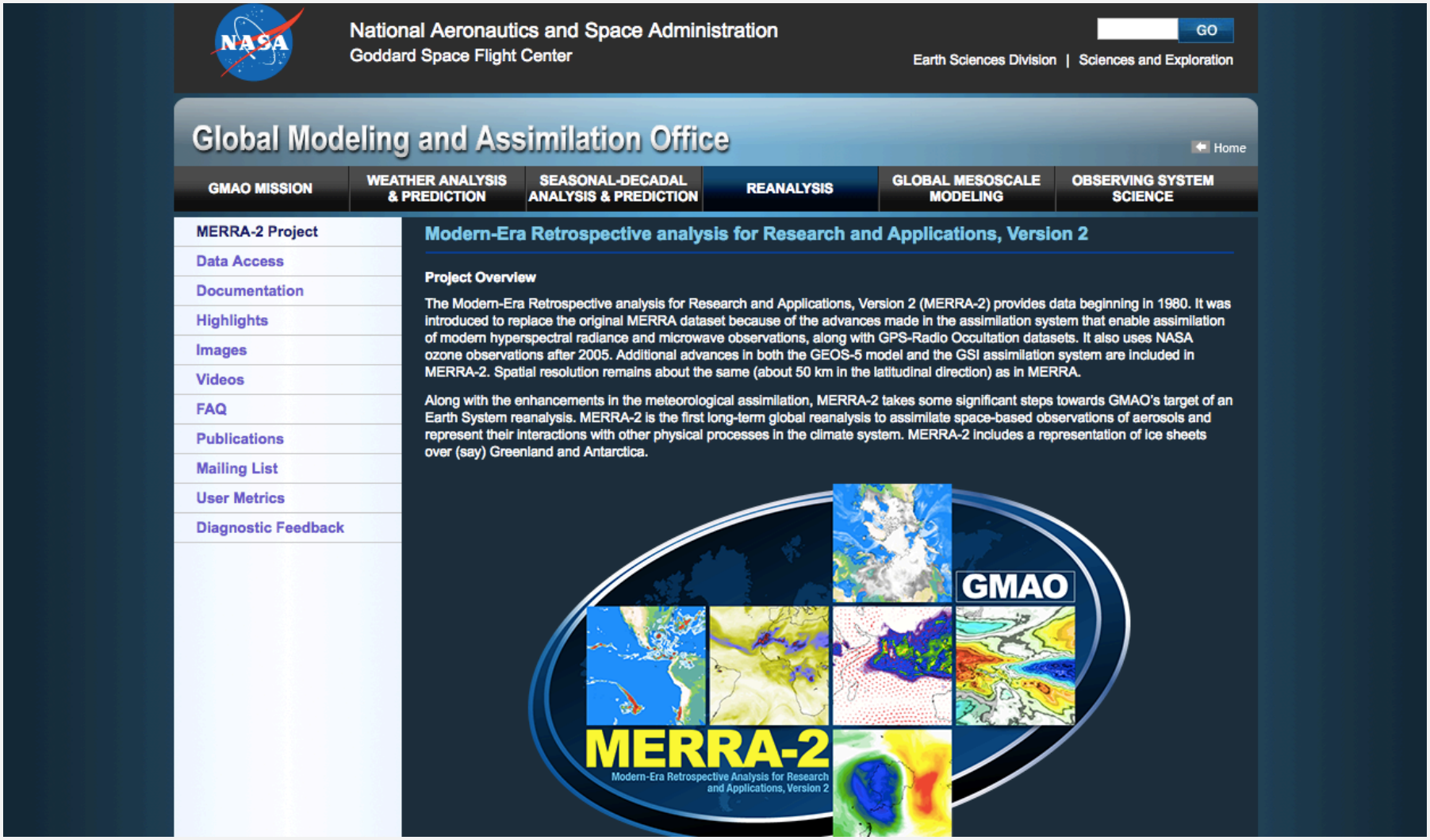
- Relatively good agreement for **sulfates**
- MERRA-2 lacks **nitrates** altogether
- Underestimation of **carbonaceous** near-urban areas
- Too much **dust**
- Too much **sea salt** at coastal stations



Data Access & Tools

MERRA -2 Webpage Tour

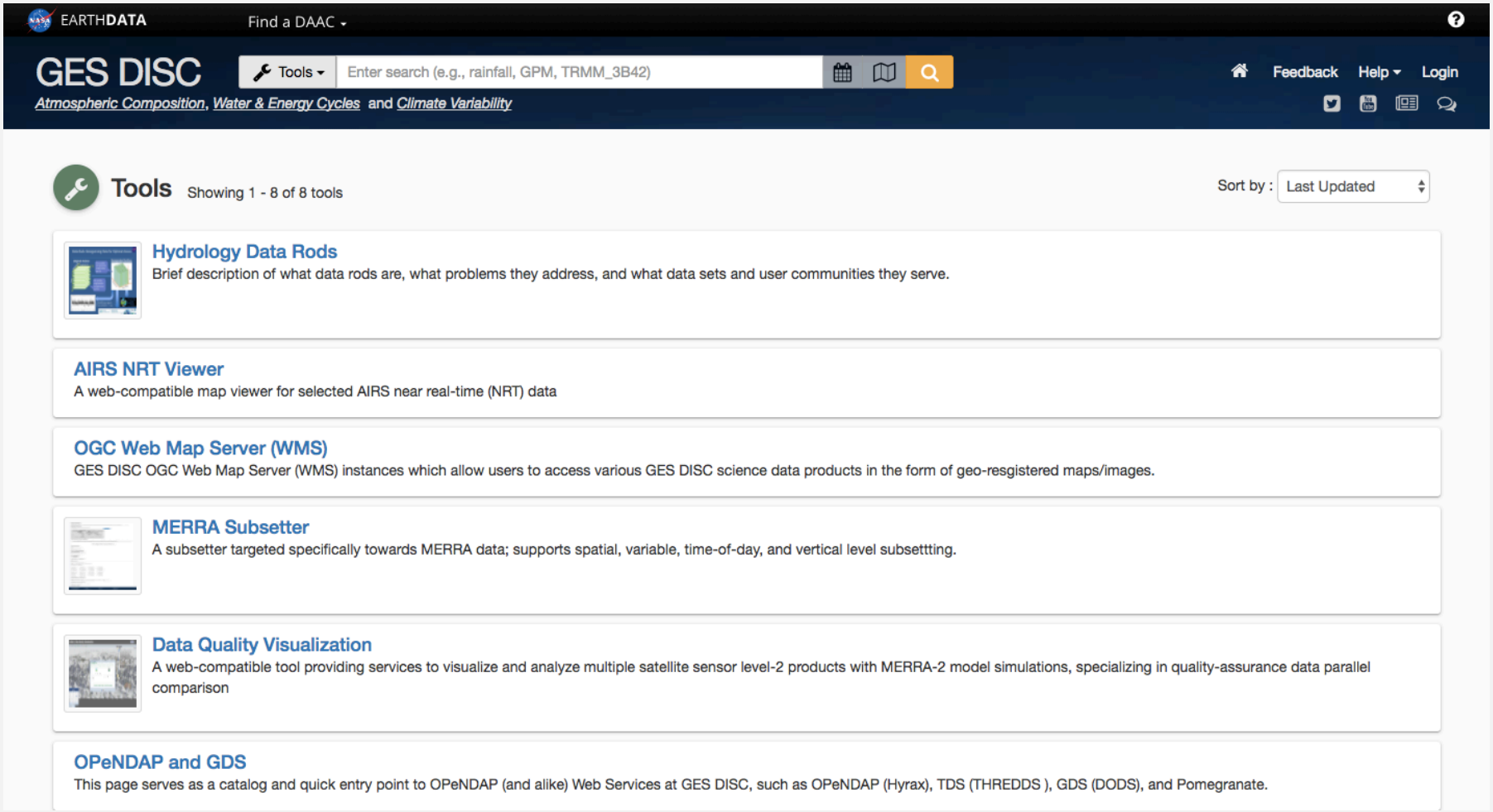
https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/



MERRA-2 Status

- MERRA-2 has officially been released. Data access through the GES DISC:
  - http://disc.sci.gsfc.nasa.gov/daac-bin/FTPSubset2.pl
  - http://disc.sci.gsfc.nasa.gov/uui/#/search/%22MERRA-2%22
- The MERRA-2 file specification document is available at:
  - http://gmao.gsfc.nasa.gov/pubs/ under the tab *Office Notes*
- NASA tech memos documenting the MERRA-2 meteorological and aerosol validation exercise will soon be available at:
  - http://gmao.gsfc.nasa.gov/pubs/ under the tab *Technical Memoranda*

MERRA Tools

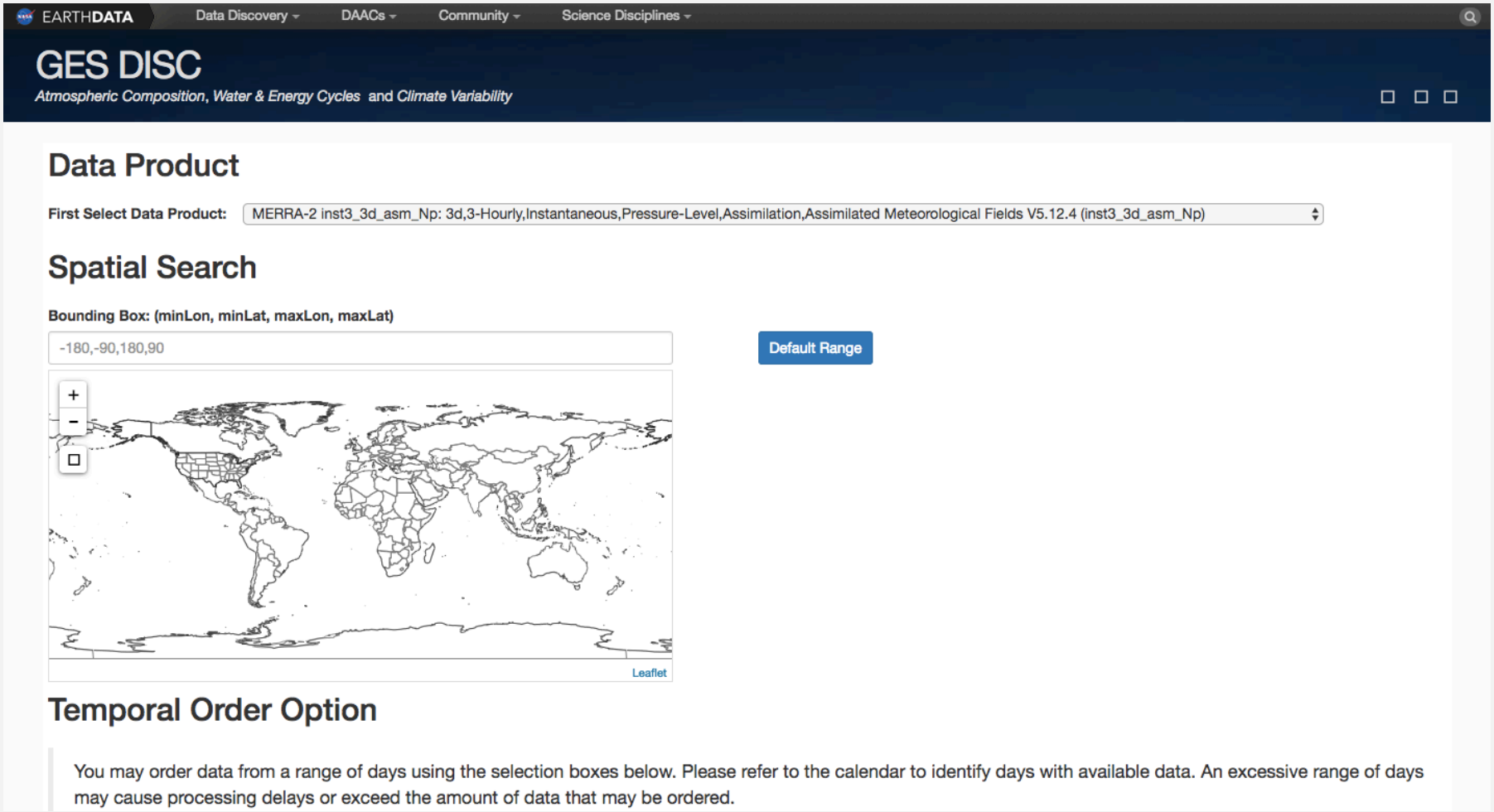

EARTHDATA
Find a DAAC
GES DISC
Tools
Enter search (e.g., rainfall, GPM, TRMM_3B42)
Feedback
Help
Login
Atmospheric Composition, Water & Energy Cycles and Climate Variability
Tools
Showing 1 - 8 of 8 tools
Sort by :
Last Updated
Hydrology Data Rods
Brief description of what data rods are, what problems they address, and what data sets and user communities they serve.
AIRS NRT Viewer
A web-compatible map viewer for selected AIRS near real-time (NRT) data
OGC Web Map Server (WMS)
GES DISC OGC Web Map Server (WMS) instances which allow users to access various GES DISC science data products in the form of geo-resgistered maps/images.
MERRA Subsetter
A subsetter targeted specifically towards MERRA data; supports spatial, variable, time-of-day, and vertical level subsettting.
Data Quality Visualization
A web-compatible tool providing services to visualize and analyze multiple satellite sensor level-2 products with MERRA-2 model simulations, specializing in quality-assurance data parallel comparison
OPeNDAP and GDS
This page serves as a catalog and quick entry point to OPeNDAP (and alike) Web Services at GES DISC, such as OPeNDAP (Hyrax), TDS (THREDDS), GDS (DODS), and Pomegranate.

OpenDAP server

Model Data

Project or Mission	Description	Web Services
LDAS	GLDAS-2, NCA-LDAS, FLDAS, and GRACE-DA-DM	OPeNDAP
	GLDAS and NLDAS	GDS
MERRA	MERRA Chemistry forcing	OPeNDAP GDS
	MERRA 2D products	OPeNDAP GDS
	MERRA 3D products	OPeNDAP GDS
MERRA-2	MERRA-2 2D products	OPeNDAP GDS
	MERRA-2 3D products	OPeNDAP GDS
NOBM	NOBM daily and monthly	OPeNDAP

MERRA-2 Data Access – GES DISC - Subsetter

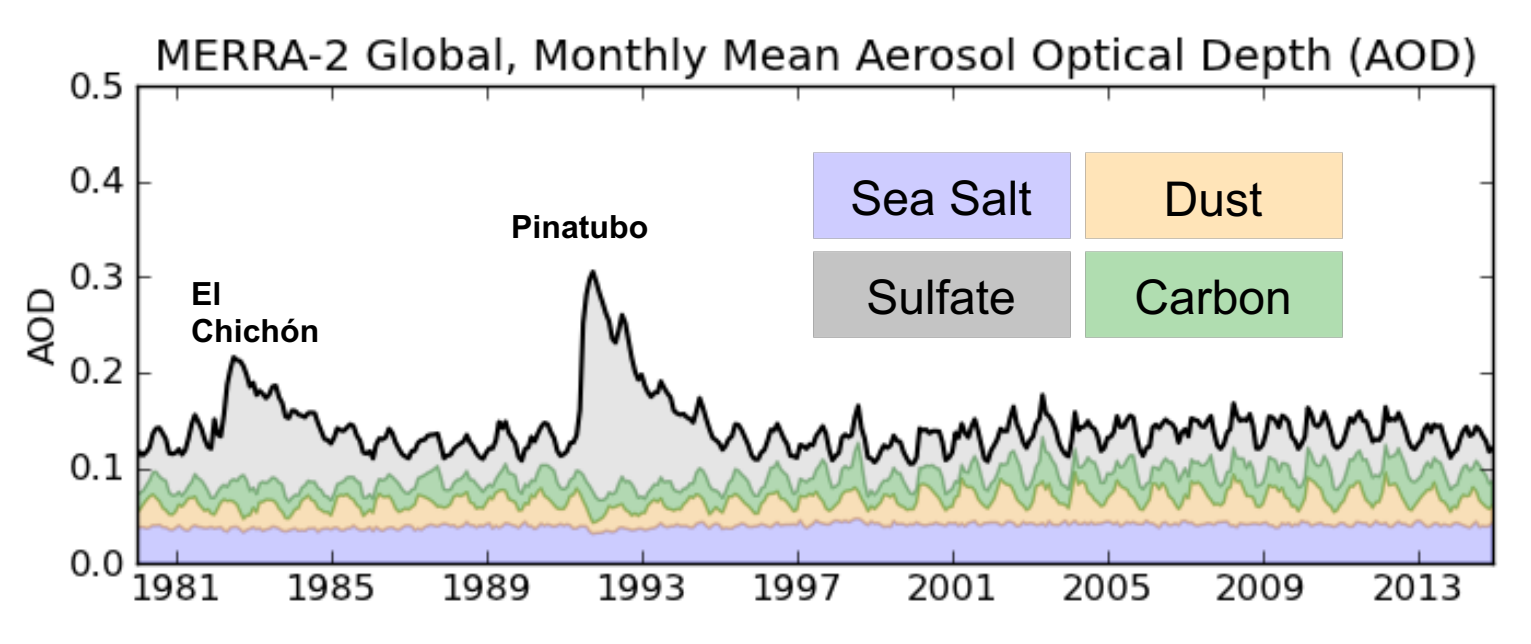


Examples – Applications

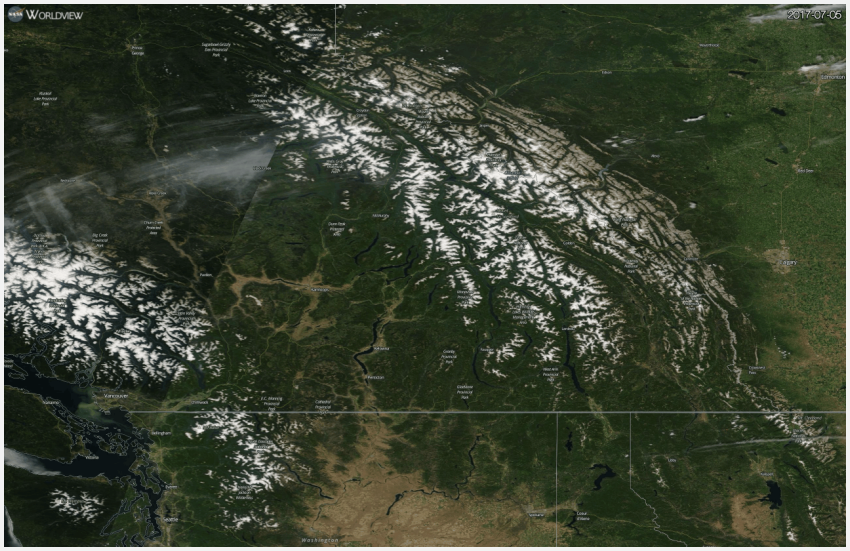
Global Mean AOD Analysis

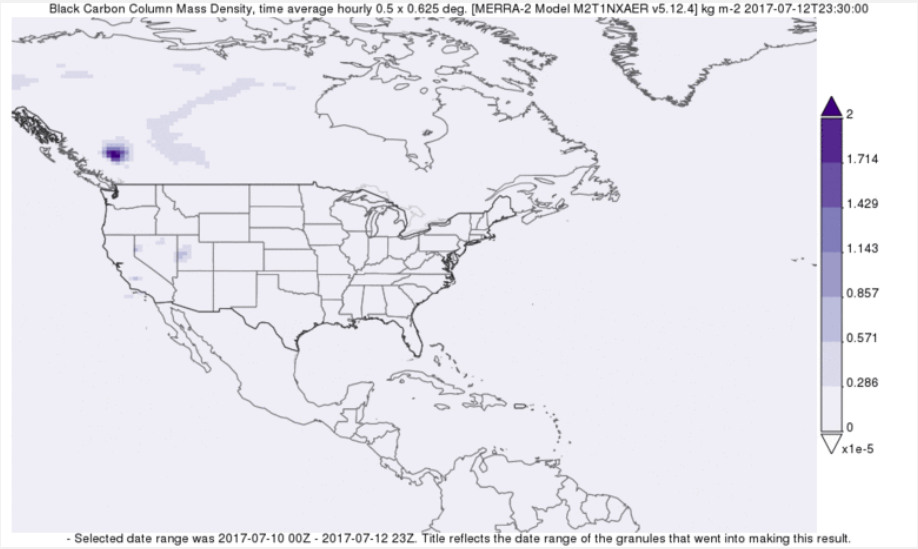
1980 – Onward

- Unique amongst its peers, the MERRA-2 reanalysis now includes an aerosol reanalysis for the modern satellite era (1980 – onward)
- Aerosols are ***coupled*** to the meteorological reanalysis (both radiatively and through emissions and loss processes)

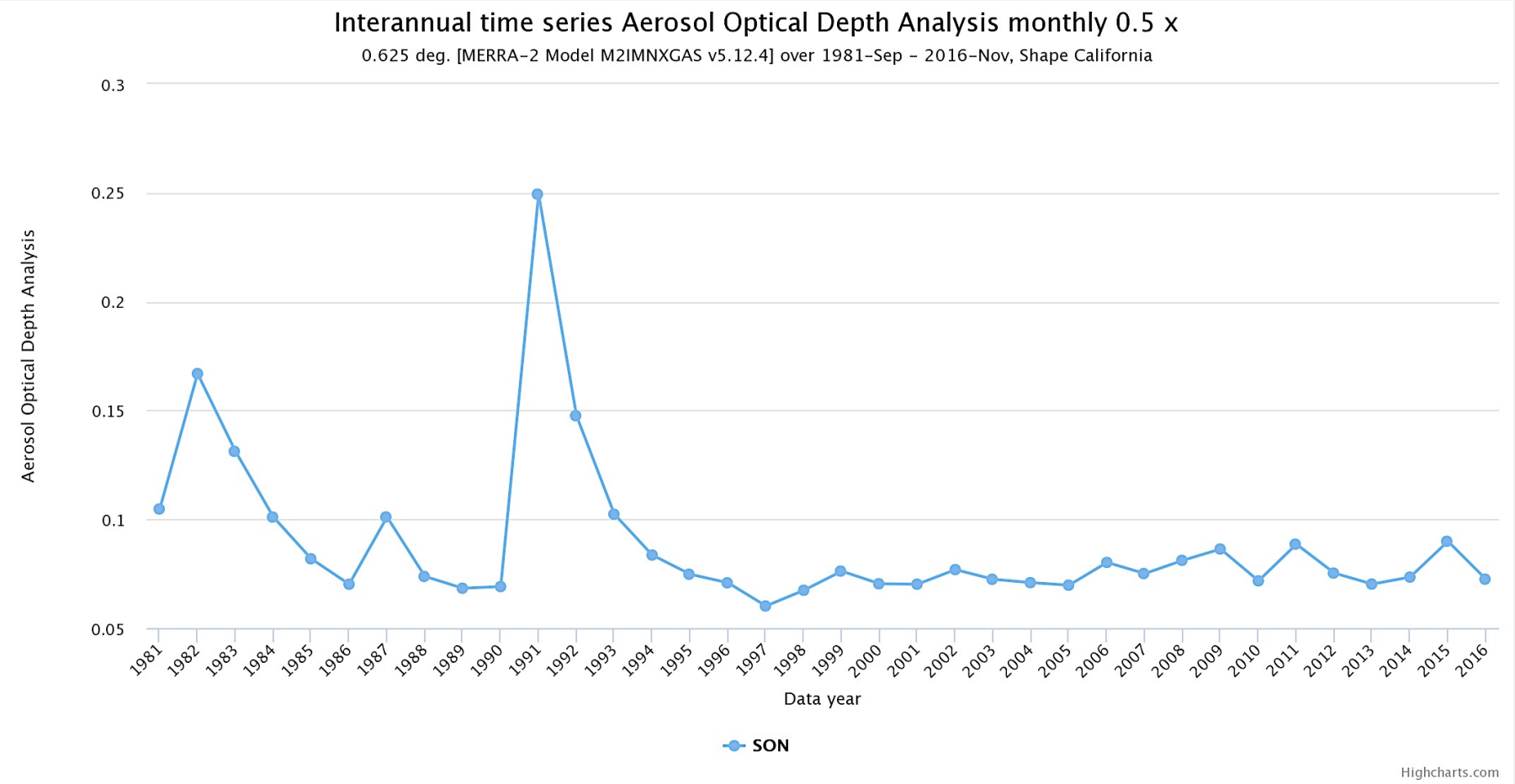


Fires – July 2017

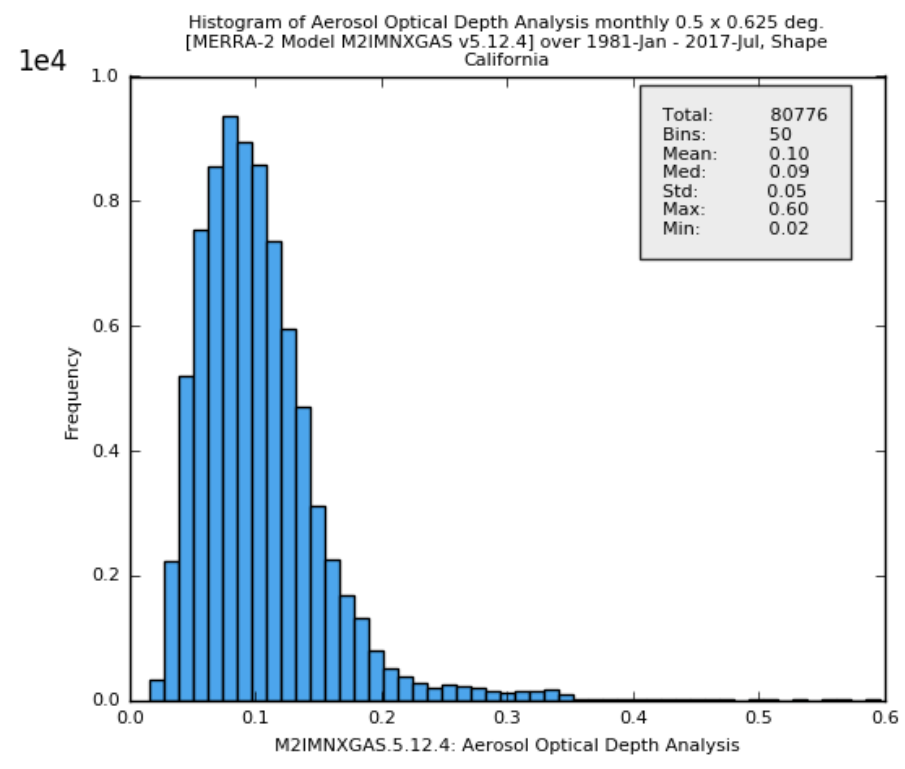


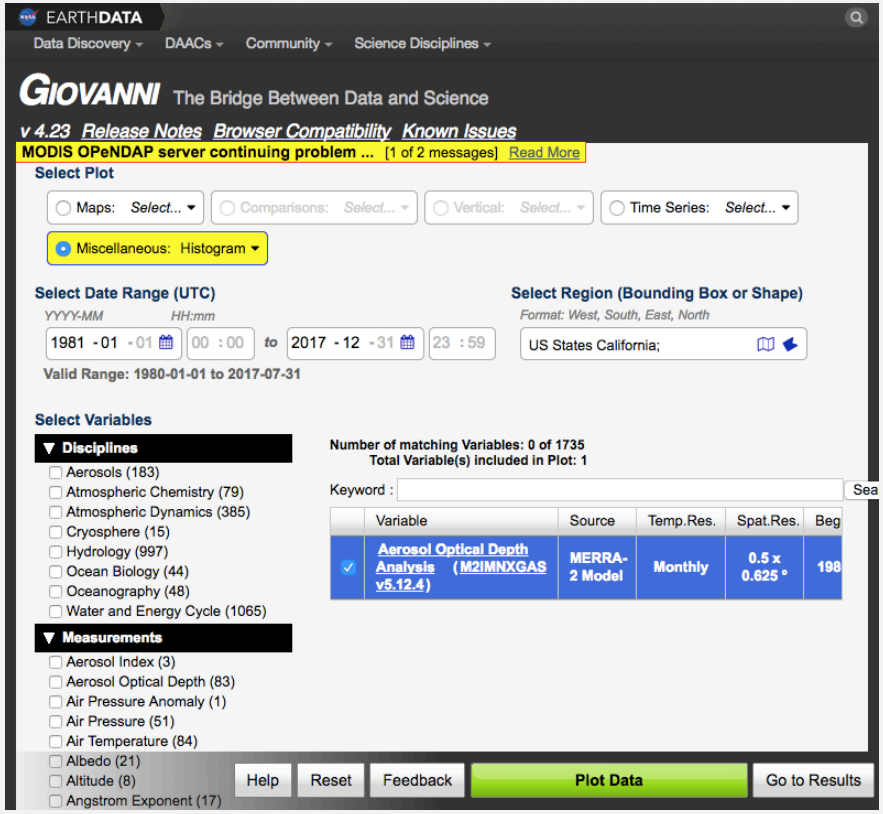


AOD Time Series Over CA

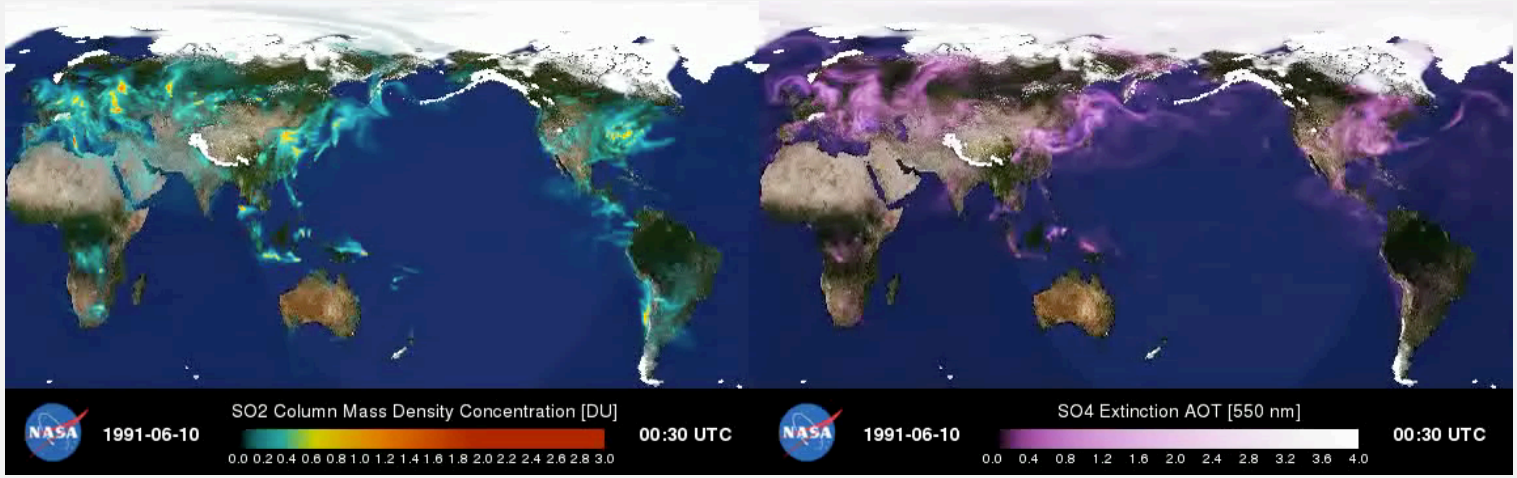


AOD Distribution Over CA





Pinatuba Eruption

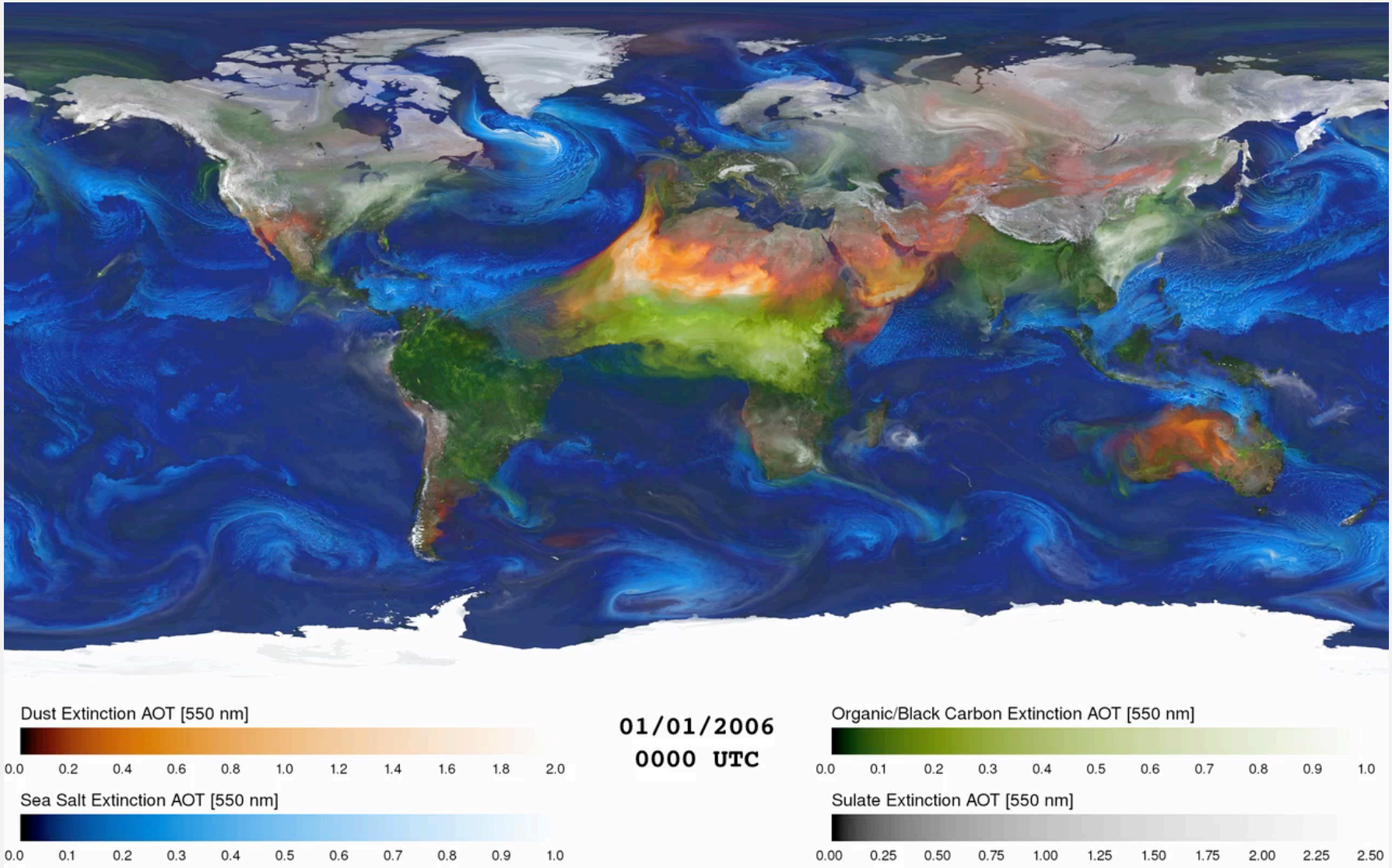


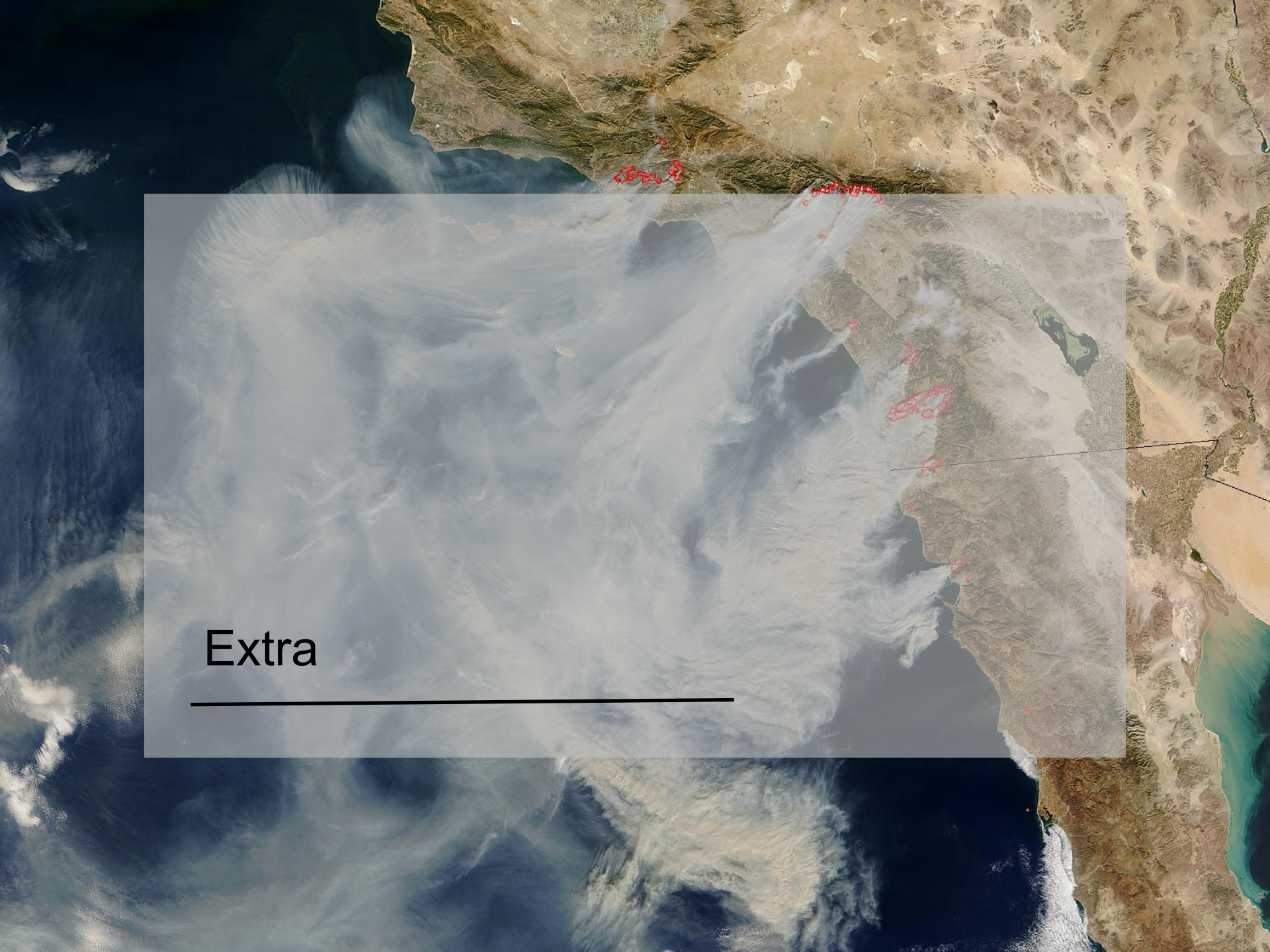
- First aerosol assimilation to include major historic volcano events like El Chichón (1982) and Pinatubo (June 1991)
- Movie shows the co-evolution of gaseous SO_2 emissions from Pinatubo (left) and formation of the sulfate aerosol plume (right) as SO_2 is converted into particles
- SO_2(g) is from emissions inventories and unconstrained by assimilation. Sulfate aerosol AOD (right) is impacted by the assimilation of total aerosol AOD

Summary

- MERRA-2 provides the first integrated aerosol-meteorology reanalysis for the satellite era
  - Aerosols impact the meteorological “first guess”
- Compared to MERRAero, MERRA-2 adds AVHRR, MISR and AERONET data to MODIS
- Caveats:
  - Monthly mean biomass burning emissions inadvertently used during 2000-2010
  - Due to forward processing constraints, MISR/AERONET have been dropped around mid/late 2014.
  - MERRA-2dd: 12.5 km downscaling coming up in 2016

7 km GEOS-5 Nature Run Global Mesoscale Simulation




Extra

GEOS-5

Earth System Model

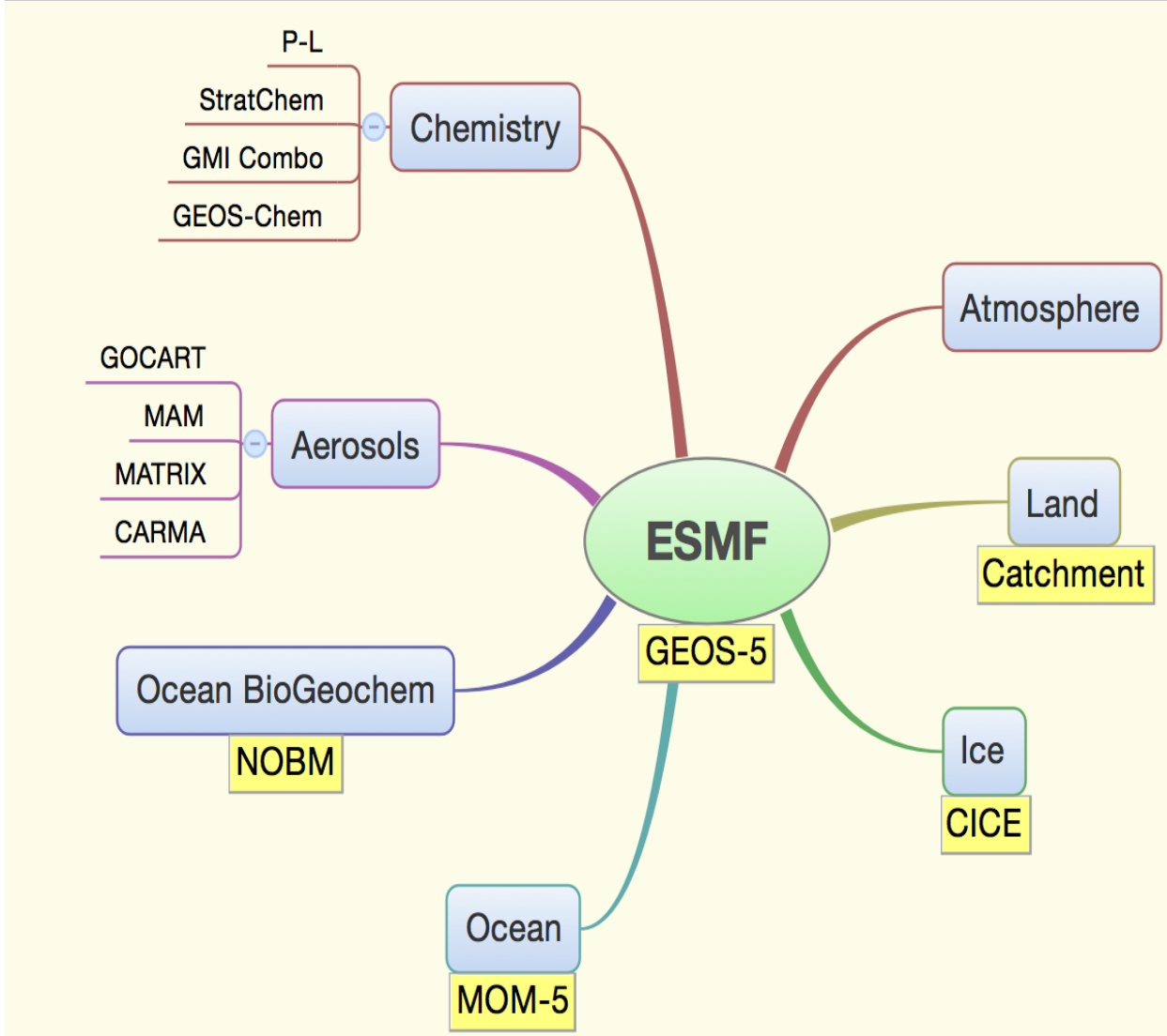
Goddard SPACE FLIGHT CENTER

Components coupling via the Earth System Model Framework (ESMF)

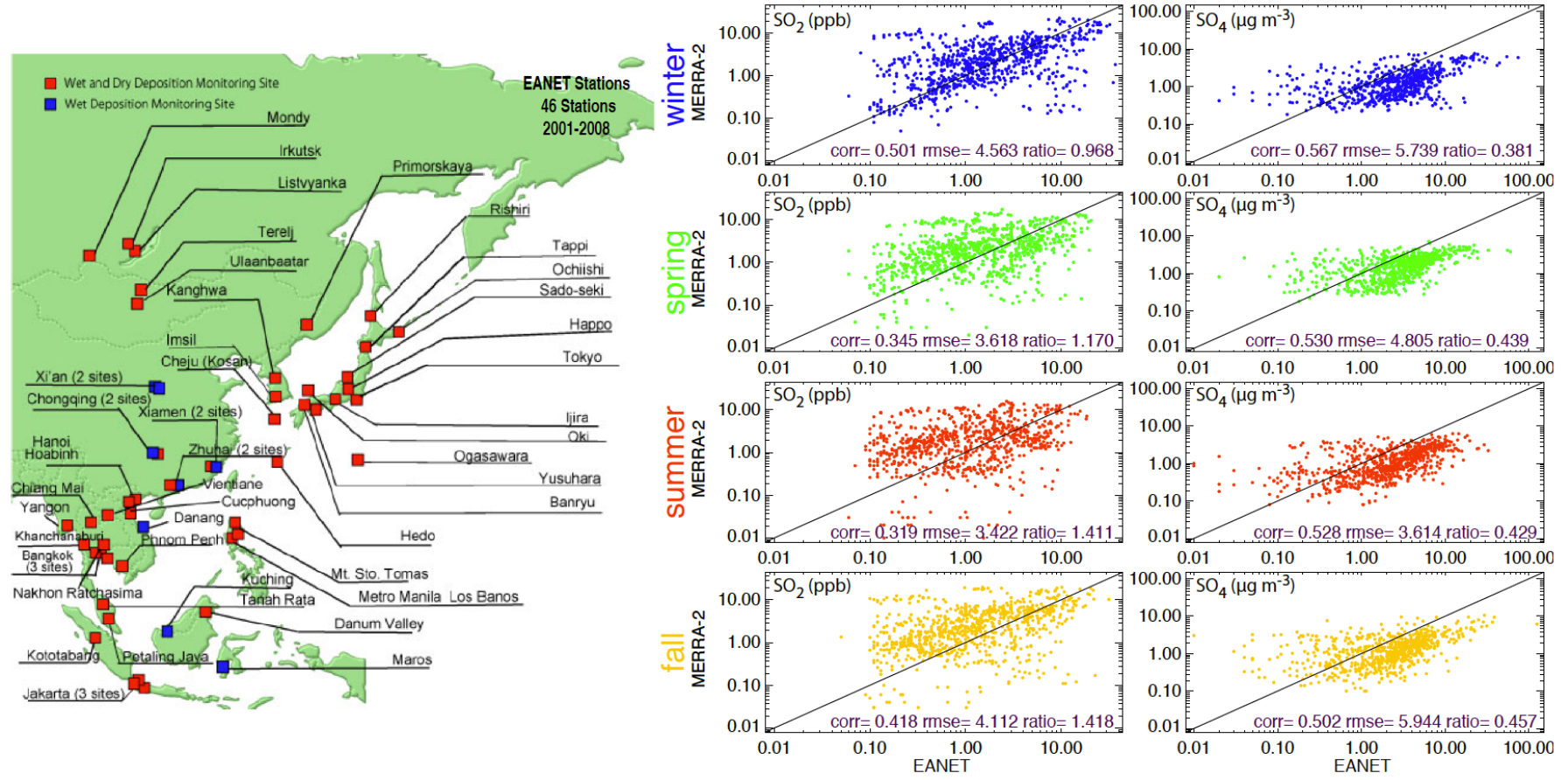
Aerosol and chemistry radiatively coupled to GCM

Applications:

- ❑ Seasonal forecasts
- ❑ Weather and aerosol NRT forecasts
- ❑ Reanalysis
- ❑ Observing System Simulation Experiments (OSSEs)



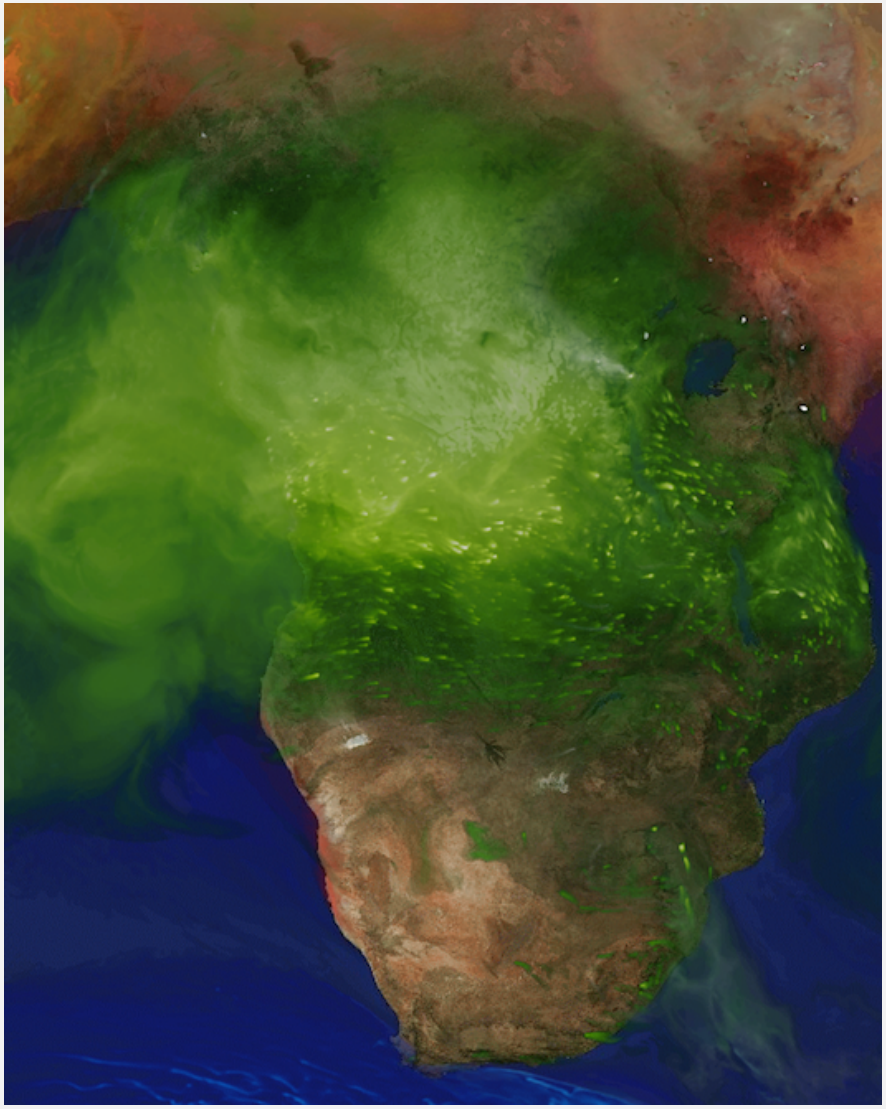
Surface Concentrations: Asia



Surface concentrations from EANET vs. MERRA-2 for 2001 – 2008

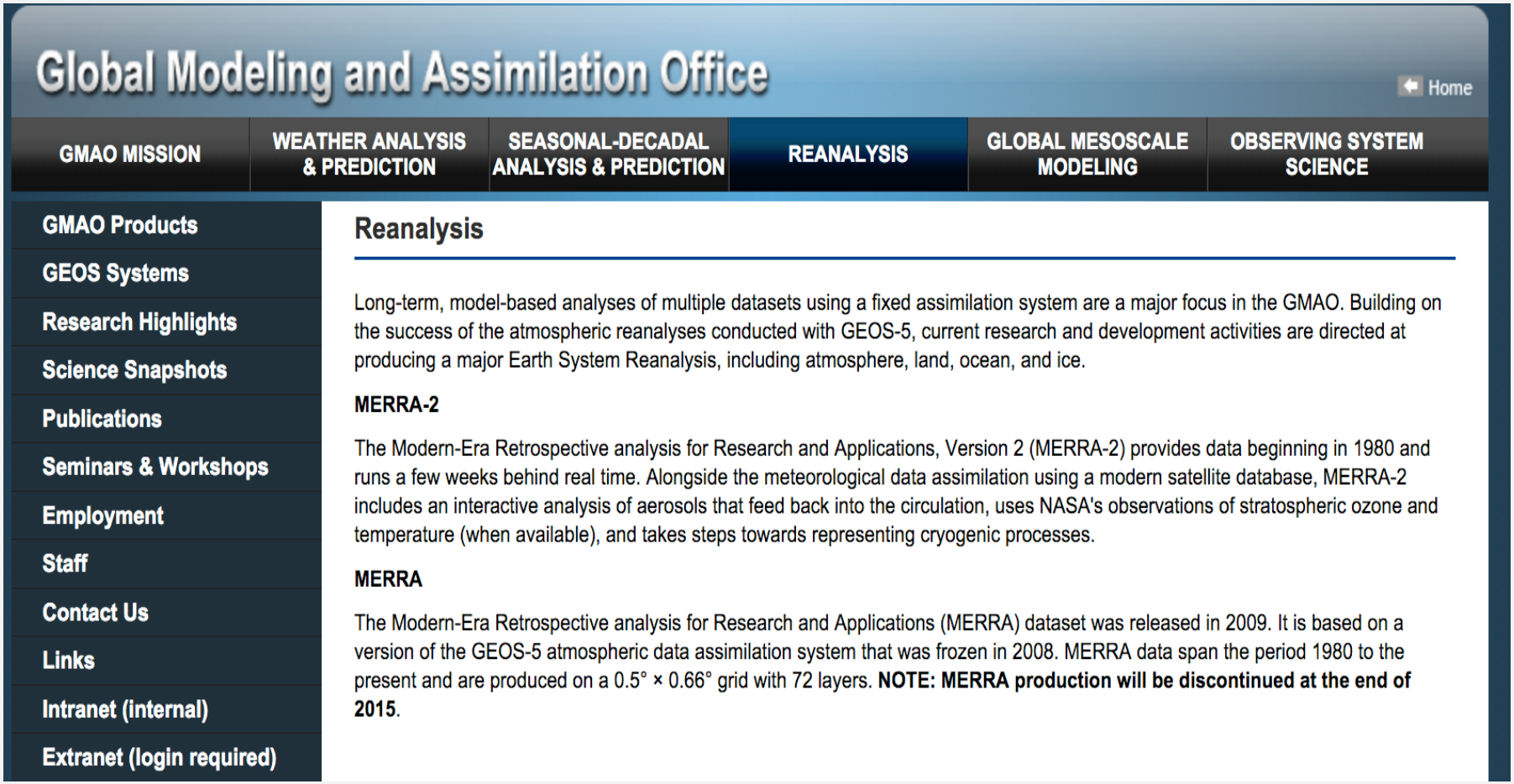
QFED: Quick Fire Emission Dataset

- Top-down algorithm based on MODIS Fire Radiative Power (AQUA/TERRA)
- FRP Emission factors tuned by means of inverse calculation based on MODIS AOD data
- Daily mean emissions, NRT
- Prescribed diurnal cycle
- In GEOS-5 BB emissions are deposited in the PBL



GEOS-5 Reanalysis

http://gmao.gsfc.nasa.gov/reanalysis



O.S.S.E

Observing **S**ystem **S**imulation **E**xperiment

Model-Based OSSE

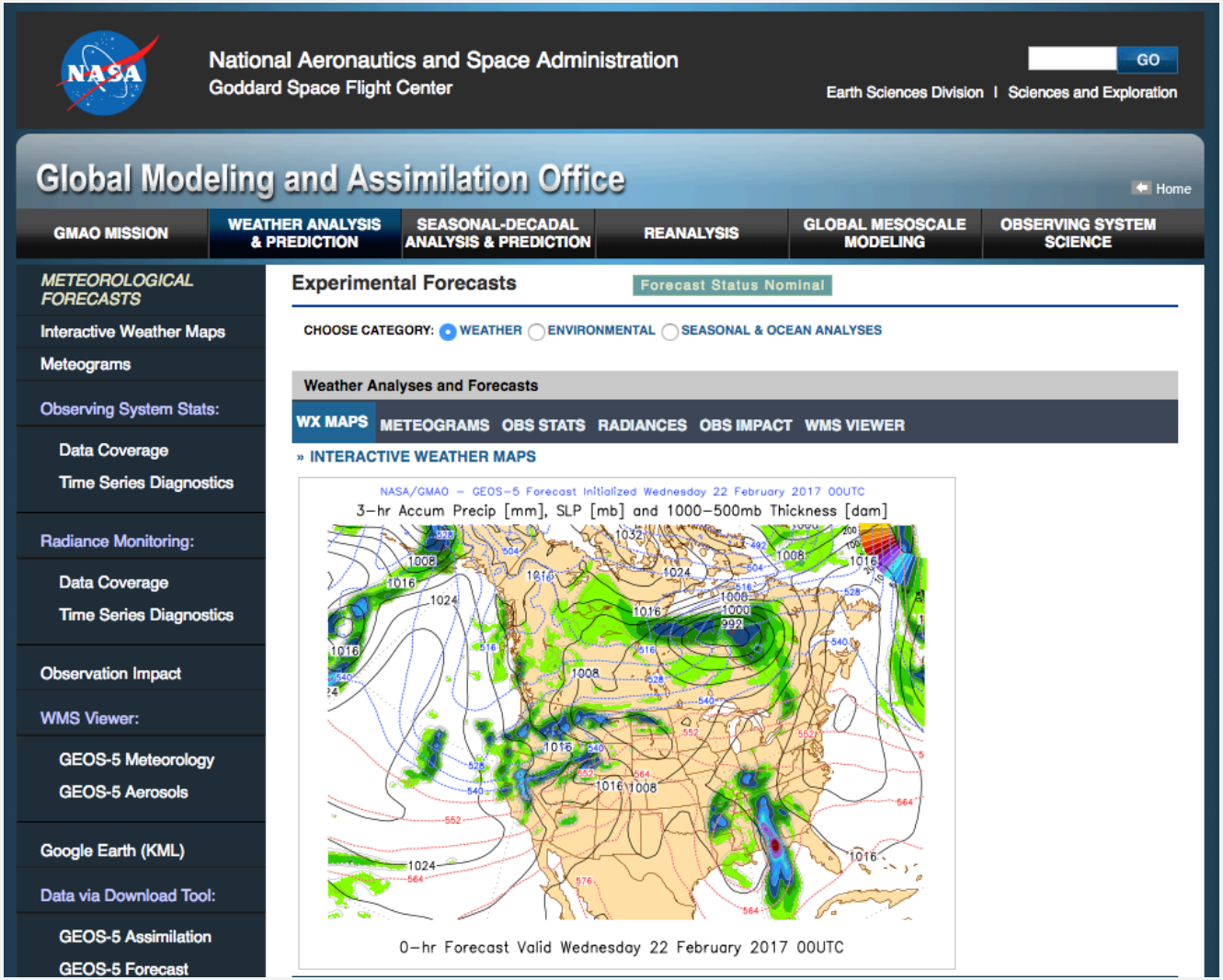
- A framework for numerical experimentation in which *observables* are simulated from fields generated by an Earth system model, including a *parameterized* description of the *observational error* characteristics
- Simulations are performed in support of an exerimental goal

GEOS-5 Nature Run Data Portal

http://gmao.gsfc.nasa.gov/projects/G5NR

GEOS-5 Forecasts

http://gmao.gsfc.nasa.gov/forecasts



G5NR Data Portal

Documentation